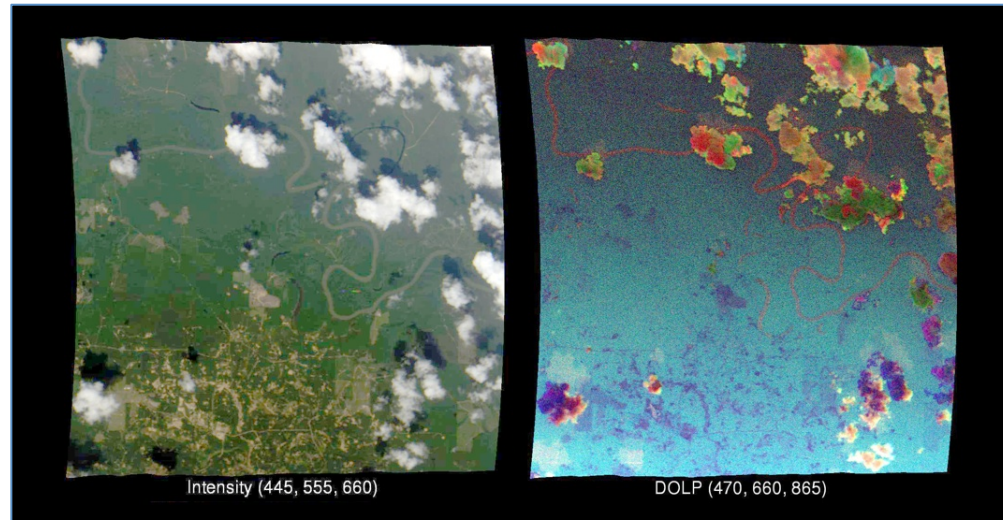


Aerosol and cloud analyses and retrieval algorithm developments in support of MSPI



ACE SWG

Greenbelt, MD

9-11 June 2014

David J. Diner

Jet Propulsion Laboratory, California Institute of Technology

and the MSPI Team



GroundMSPI and AirMSPI

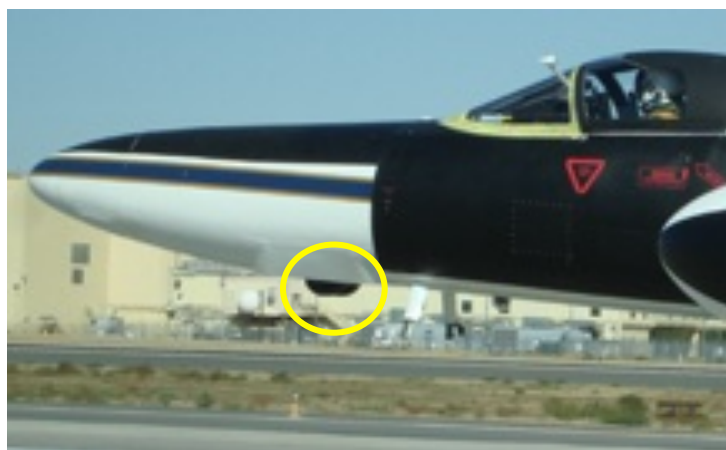


GroundMSPI is a portable field instrument

2-axis gimbal provides elevation and azimuthal scanning of both the surface and sky

Employed for developing models of surface boundary condition used in aerosol retrievals

Spectral bands: 355, 380, 445, 470*, 555, 660*, 865*, 935 nm (*polarimetric)



AirMSPI flies in the nose of NASA's ER-2 aircraft

1-axis gimbal provides multi-angle viewing between $\pm 67^\circ$

Being used for developing retrieval algorithms

Aerosol retrieval algorithm development

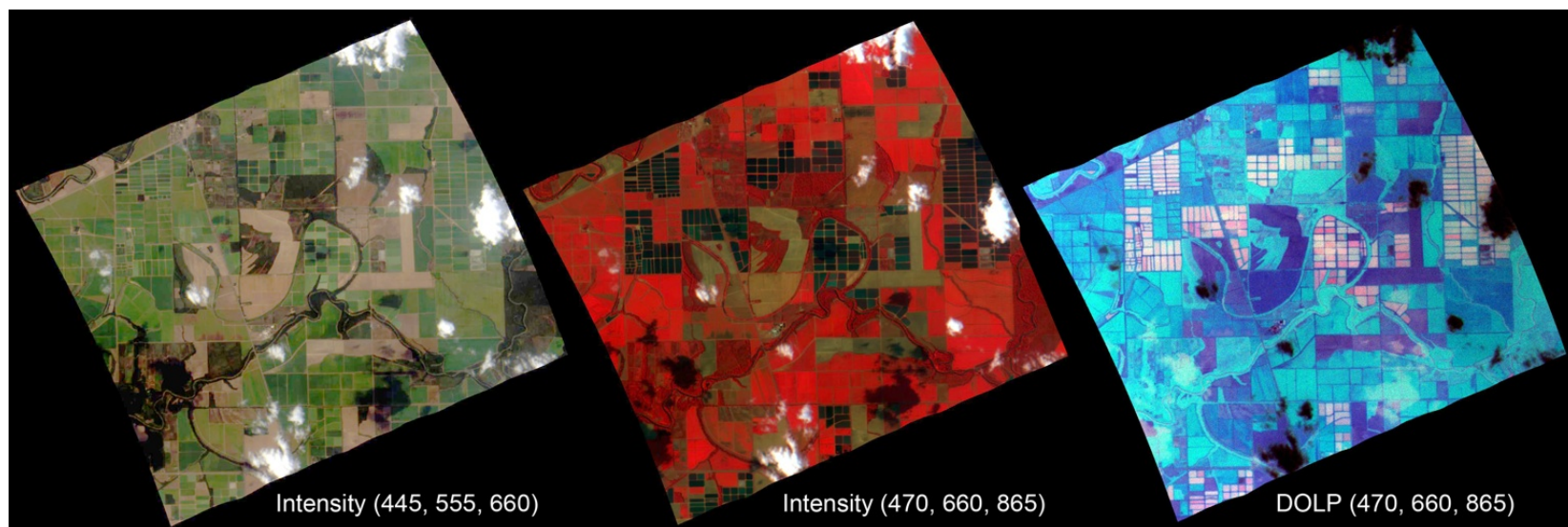
- JPL-developed RT code used as basis of aerosol retrieval algorithm, with support from Oleg Dubovik (Univ. of Lille)
- GRASP code developed by Oleg is being evaluated in parallel

	JPL code (ocean, land)	GRASP (land)
Forward RT calculation method	Markov Chain + Doubling/Adding	Successive Orders of Scattering
Aerosol size model	Multi-bin, bimodal	Multi-bin, multi-modal*
Particle shape	Spherical	Spherical, spheroidal
Refractive index	Mode dependent	Mode independent
Land surface model	Modified RPV + Fresnel microfacet distribution	RPV + Maignan model
Ocean surface model	Cox-Munk + bio-optical*	Cox-Munk*
Language	Matlab (for development), C++*	Fortran
Speed	Speedup methods required, in study*	Fast

*in development/testing

Smoke aerosols near Leland, Mississippi

AirMSPI nadir imagery, 9 Sept 2013, 2116 UTC

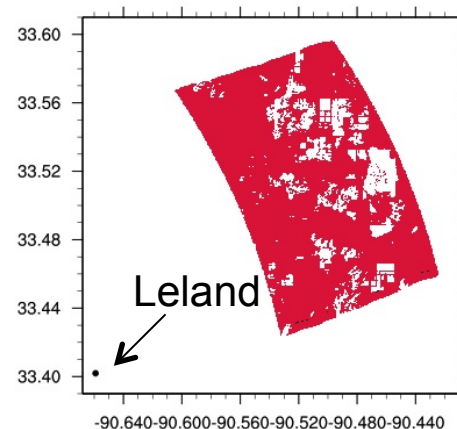
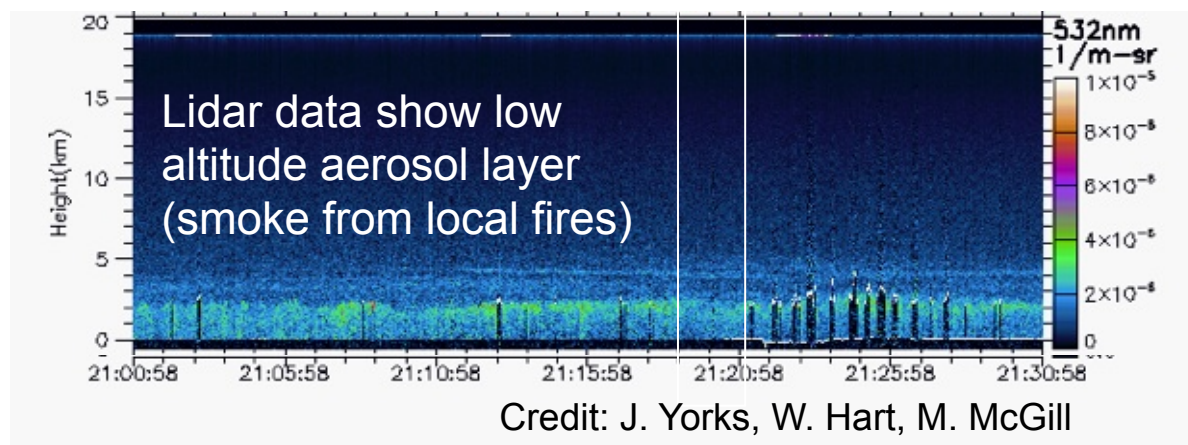


Absorbing Aerosol Index calculated using UV bands

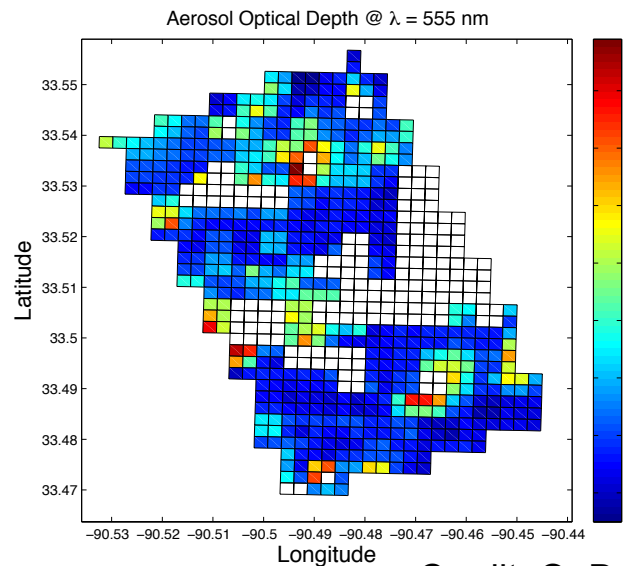
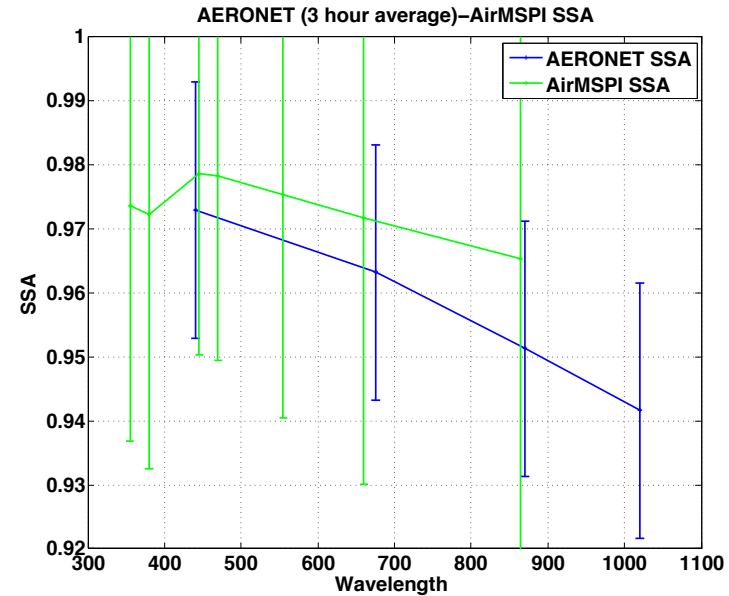
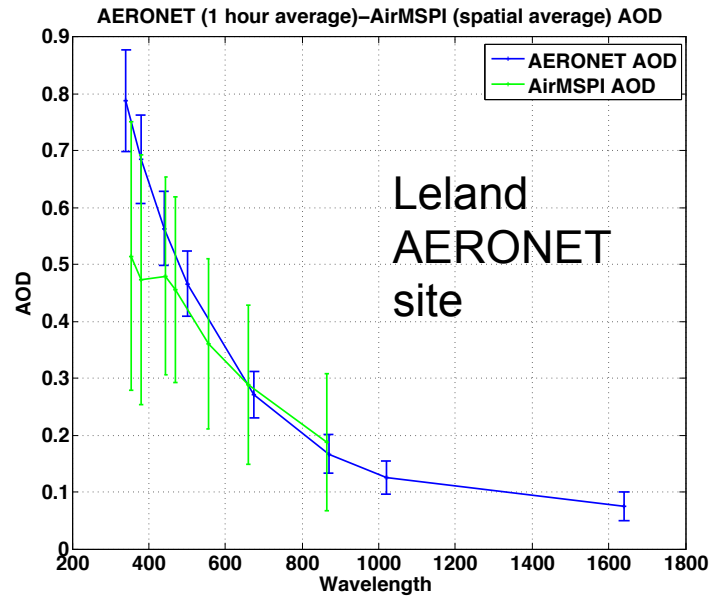
$$A.I. = -100 \times [\log_{10}(I_{355}/I_{380})_{\text{meas}} - \log_{10}(I_{355}/I_{380})_{\text{calc}}]$$

indicates the presence of absorbing aerosols

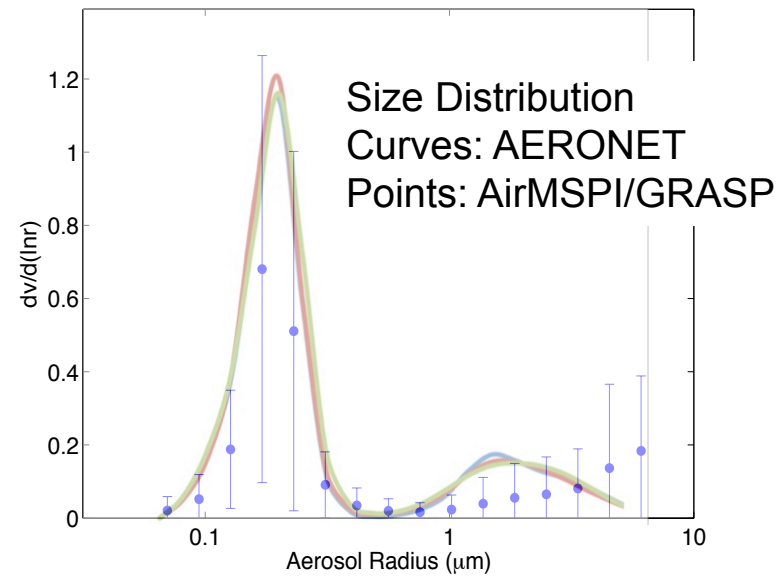
CPL backscatter



Aerosol retrieval using GRASP

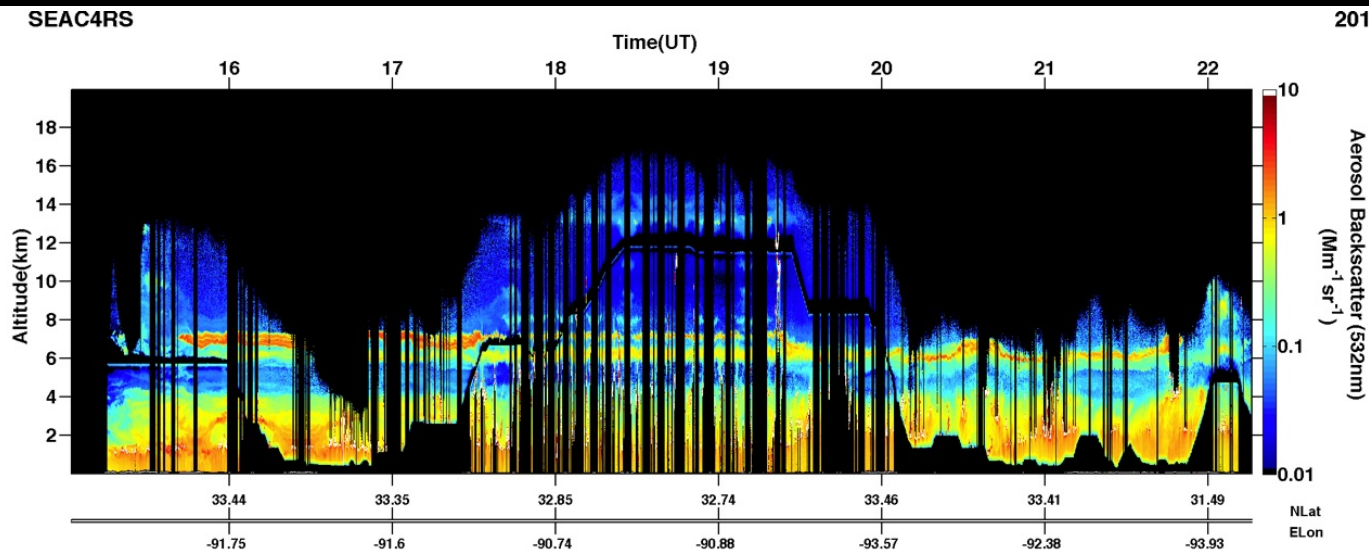
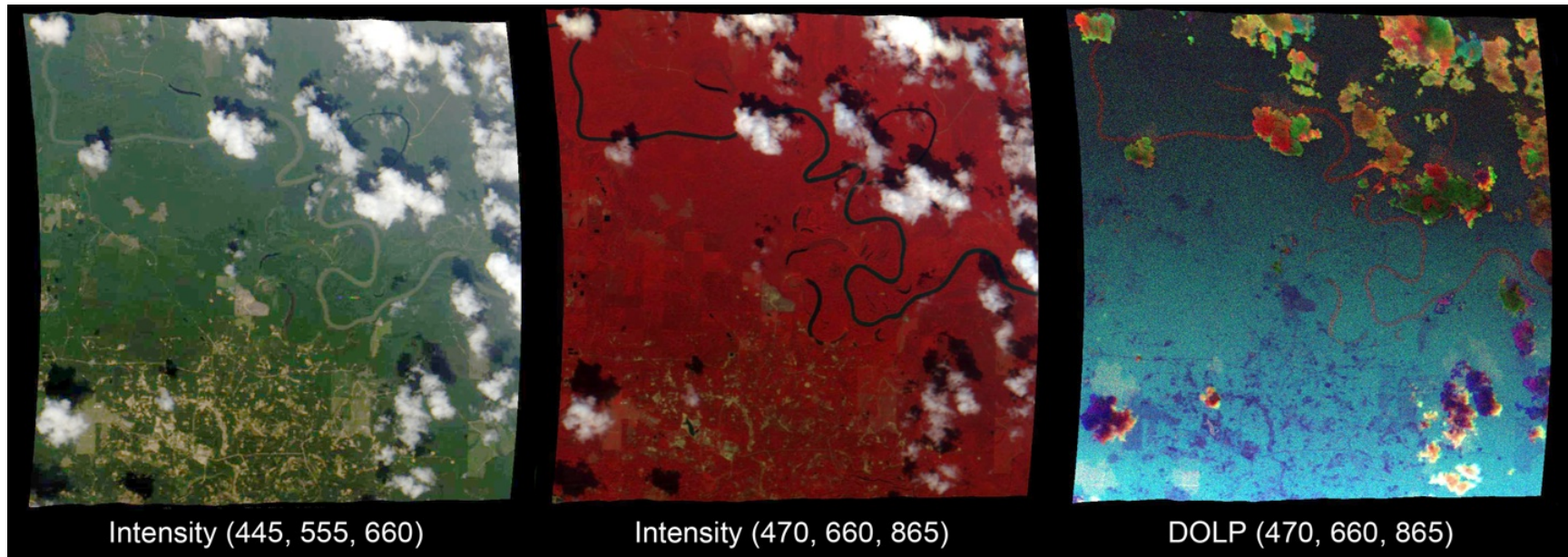


Credit: O. Dubovik



Smoke aerosols in Southern Arkansas

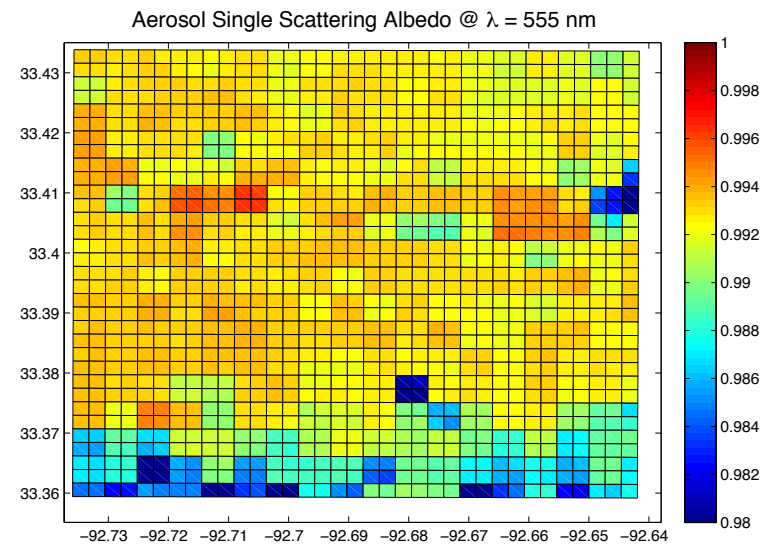
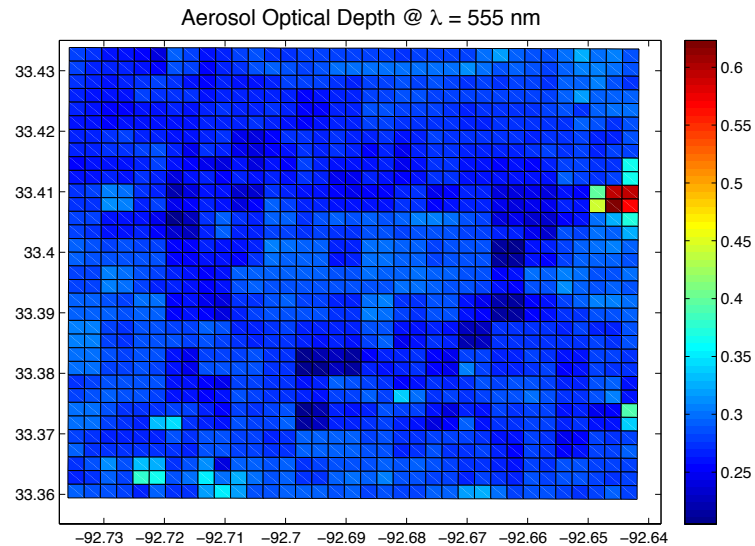
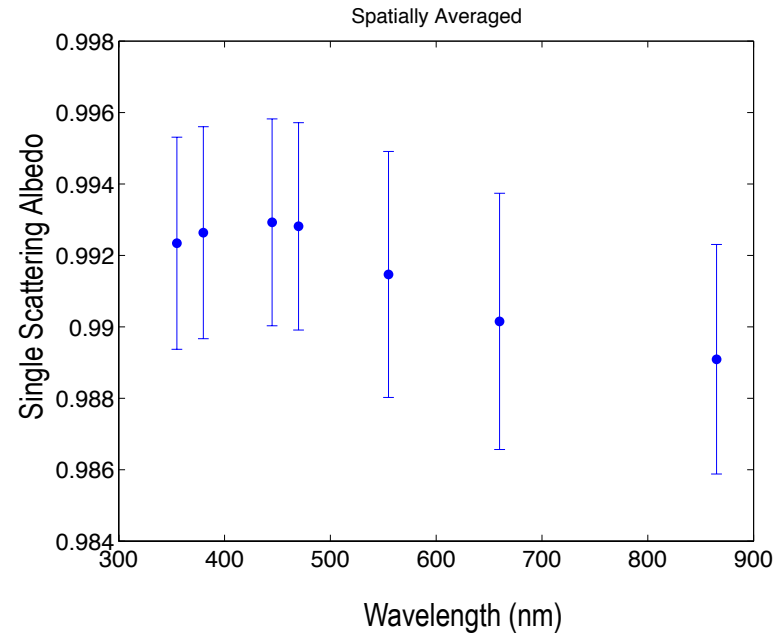
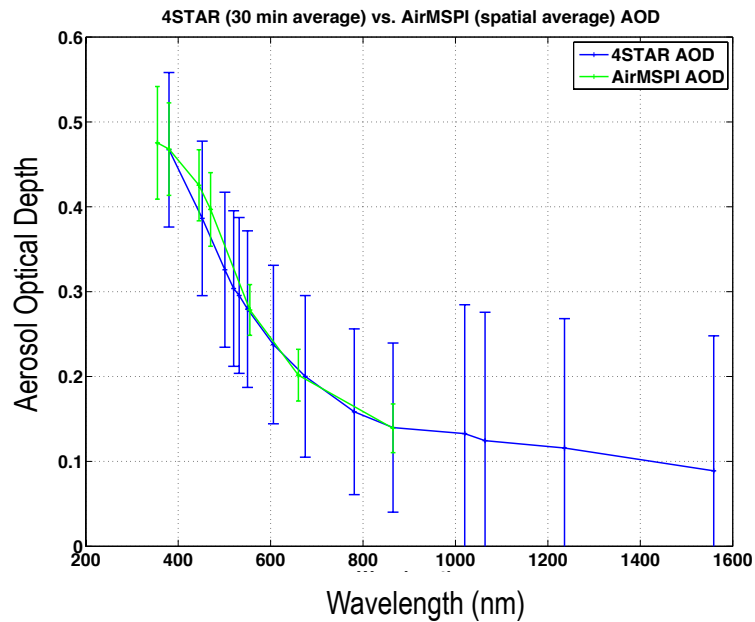
AirMSPI 29.1° aft imagery, 23 Aug 2013, 1636 UTC



HSRL (DC-8)
backscatter
profile shows
elevated
smoke layer
near 7 km

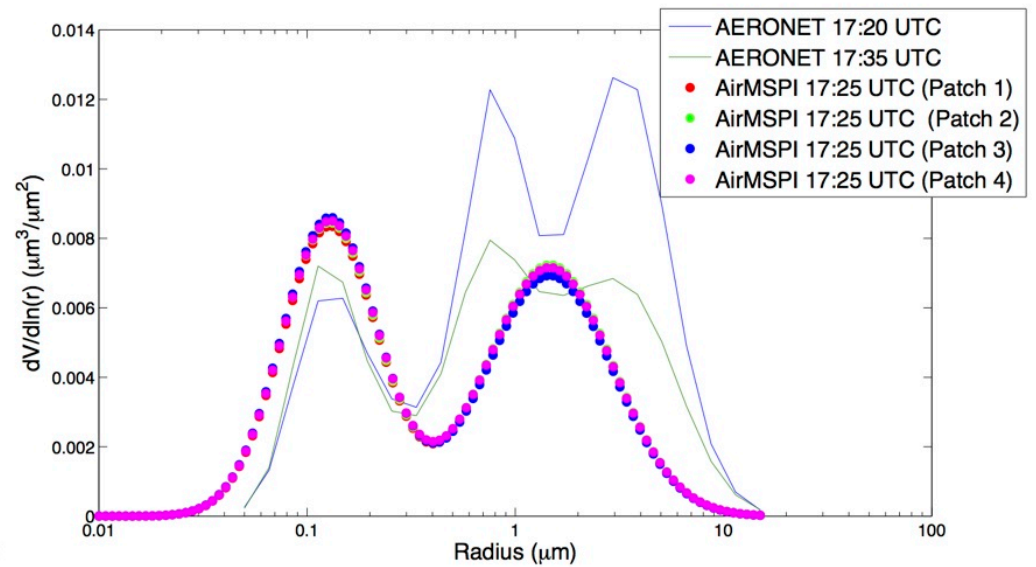
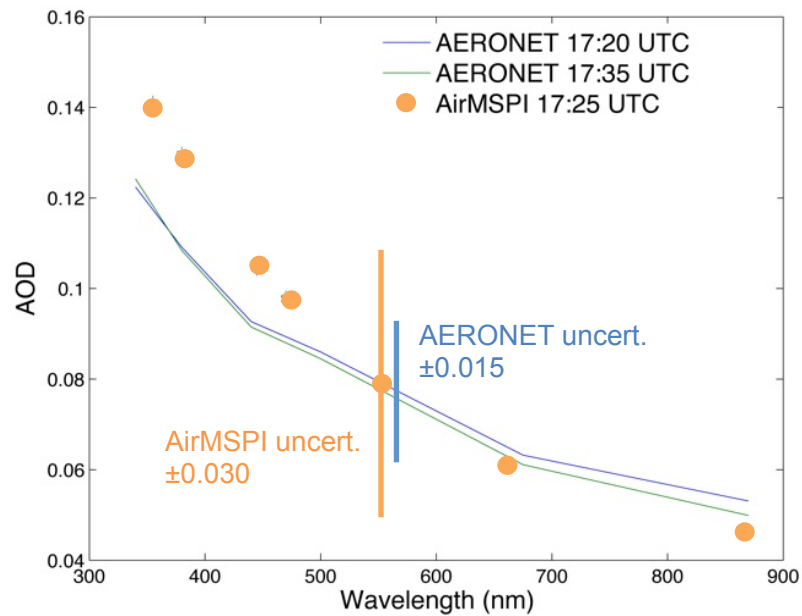
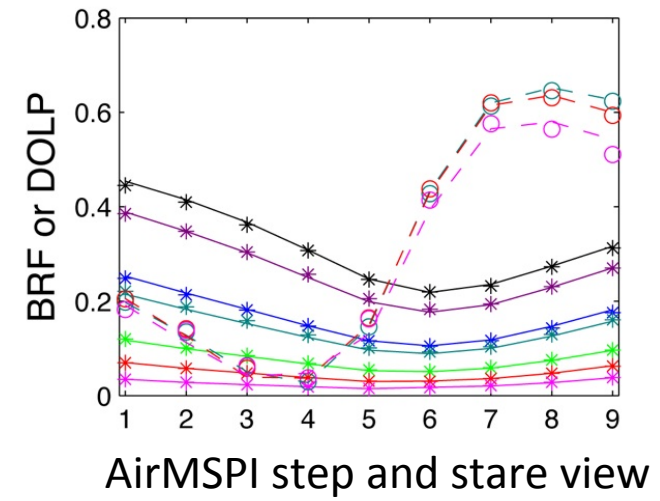
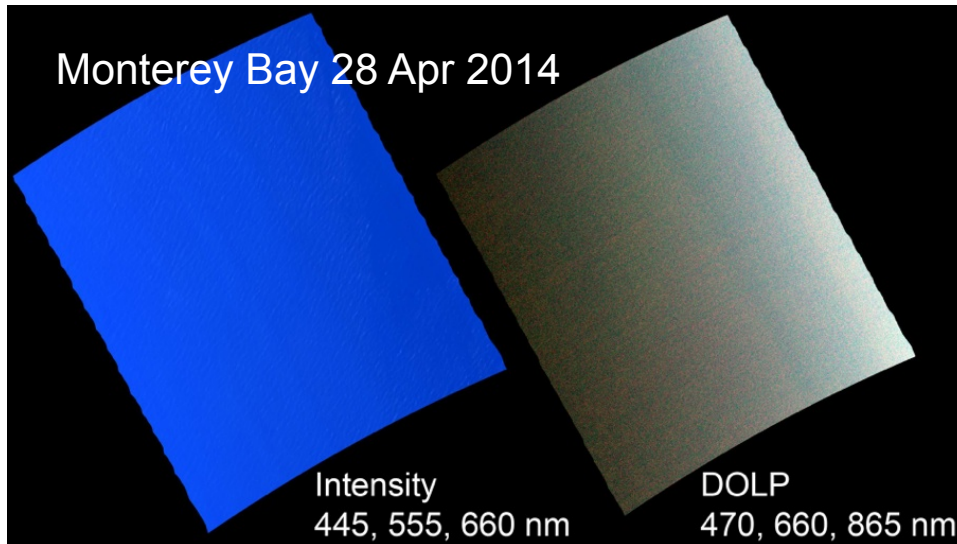
Credit: C.Hostetler, J. Hair, R. Ferrare

Aerosol retrieval using GRASP

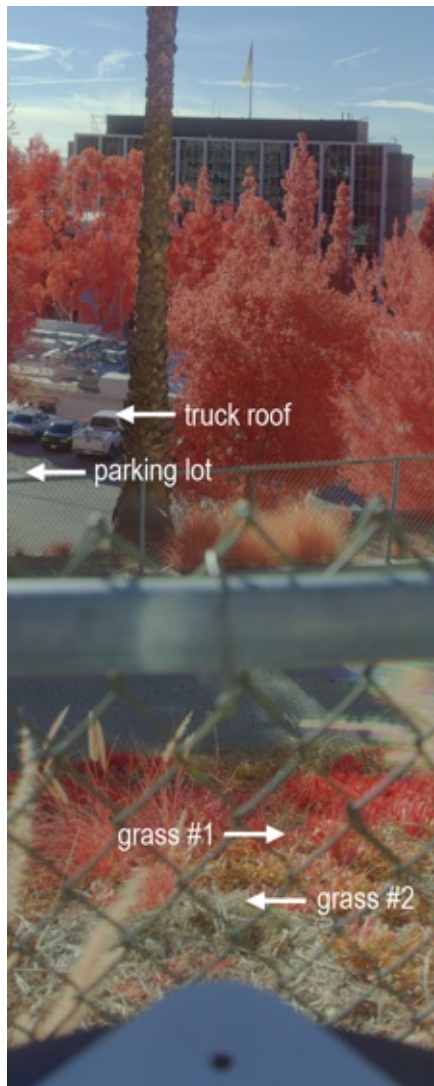


Credit: O. Dubovik

Aerosol retrieval using MarCh



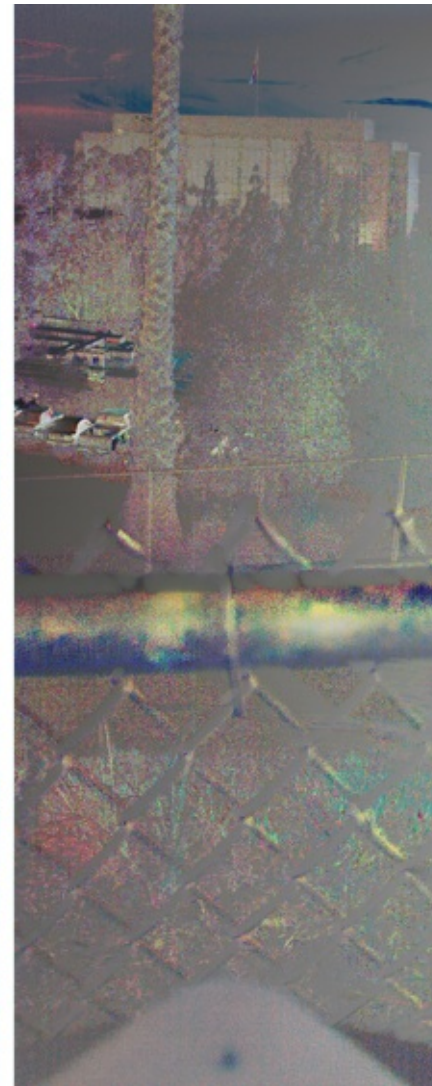
GroundMSPI data analysis



Intensity (I)



$\text{DOLP} = \frac{(Q^2 + U^2)^{1/2}}{I}$



$\text{AOLP} = \frac{1}{2} \text{atan} (U/Q)$

Diner et al. (2012)

470 nm
660 nm
865 nm

Parametric surface model

Surface BRDF is modeled as a volumetric depolarizing scattering term plus a polarizing term consisting of reflection from an angular distribution of specularly reflecting facets.

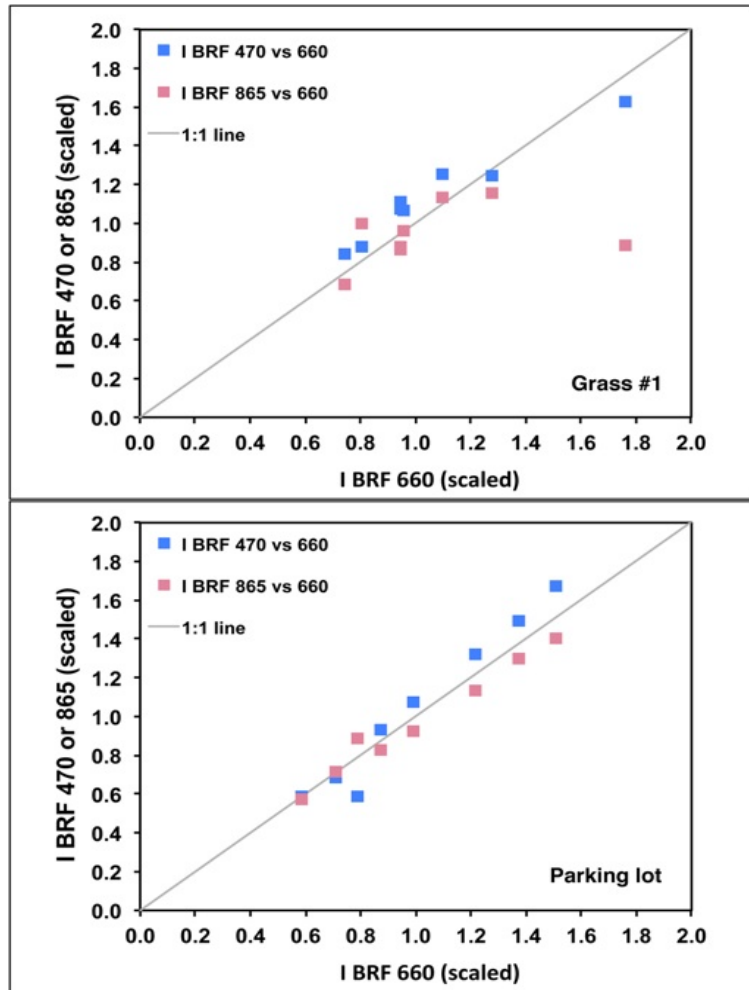
$$\mathbf{f}_\lambda(-\mu, \mu_0, \phi - \phi_0) = \frac{a_\lambda}{\pi} [(\mu + \mu_0)\mu_0\mu]^{k-1} \exp[b \cdot \cos \Omega] \cdot \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} + \xi \frac{p(\beta)}{4 \cos \beta \cos \theta \cos \theta_0} \mathbf{M}(-\alpha) \mathbf{F}(\gamma, n_r, n_i) \mathbf{M}(\alpha_0)$$

all terms spectrally neutral except a_λ

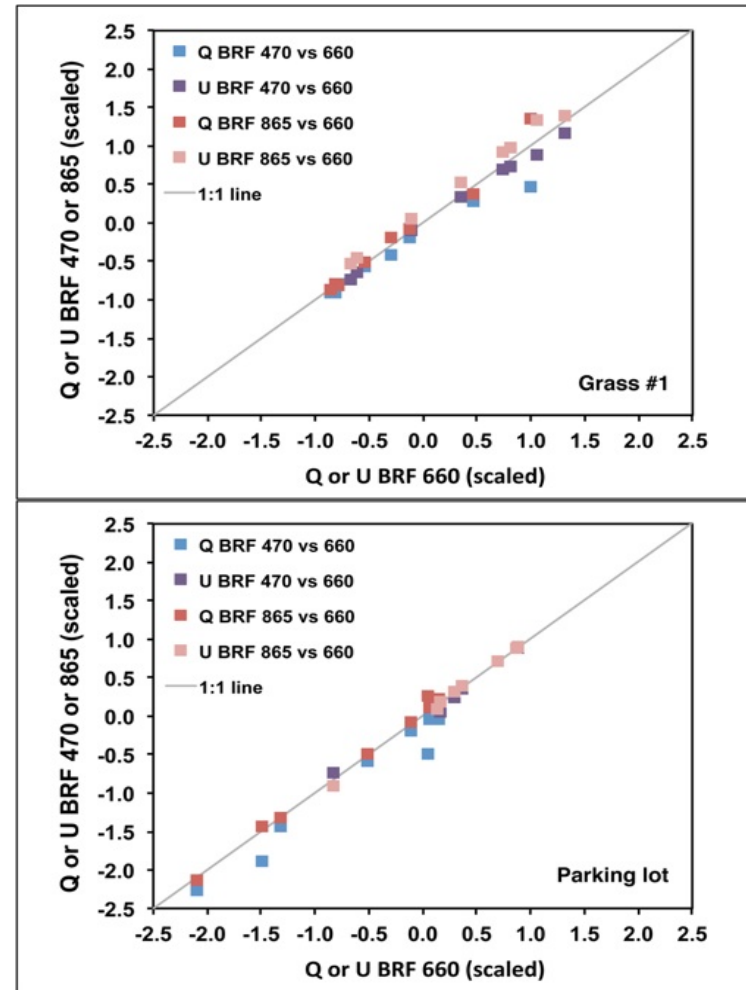
Modified Rahman-Pinty-Verstraete

Fresnel facets with angular probability distribution in tilt angle β

GroundMSPI supports spectral invariance assumption



Angular shape of intensity BRF is spectrally invariant (used in MISR retrievals)

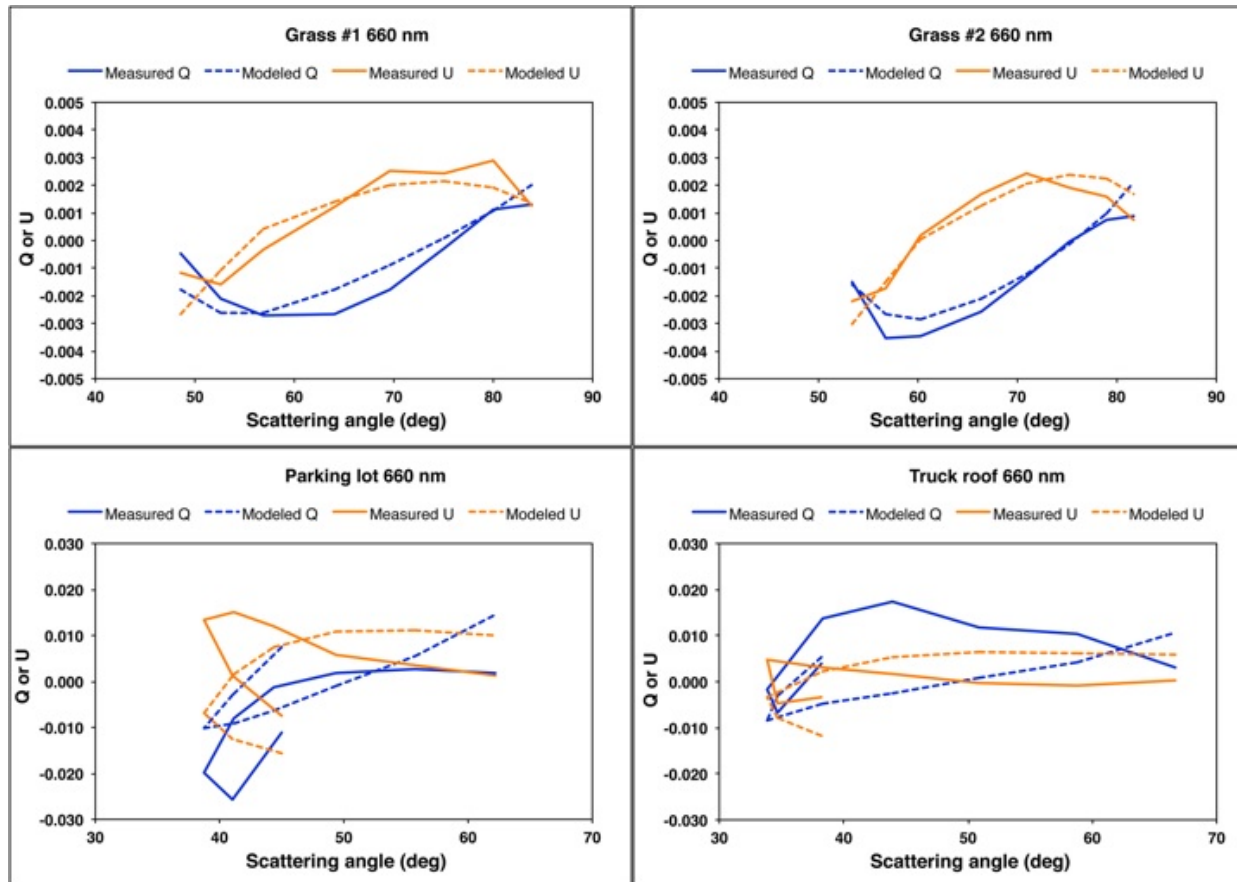


Magnitude and angular shape of polarized BRF is spectrally invariant (to be used in MSPI retrievals)

Valuable constraints on aerosol retrievals

GroundMSPI tests of polarized surface model

Randomly oriented facets reflect sunlight and skylight assuming a single specular (Fresnel) reflection

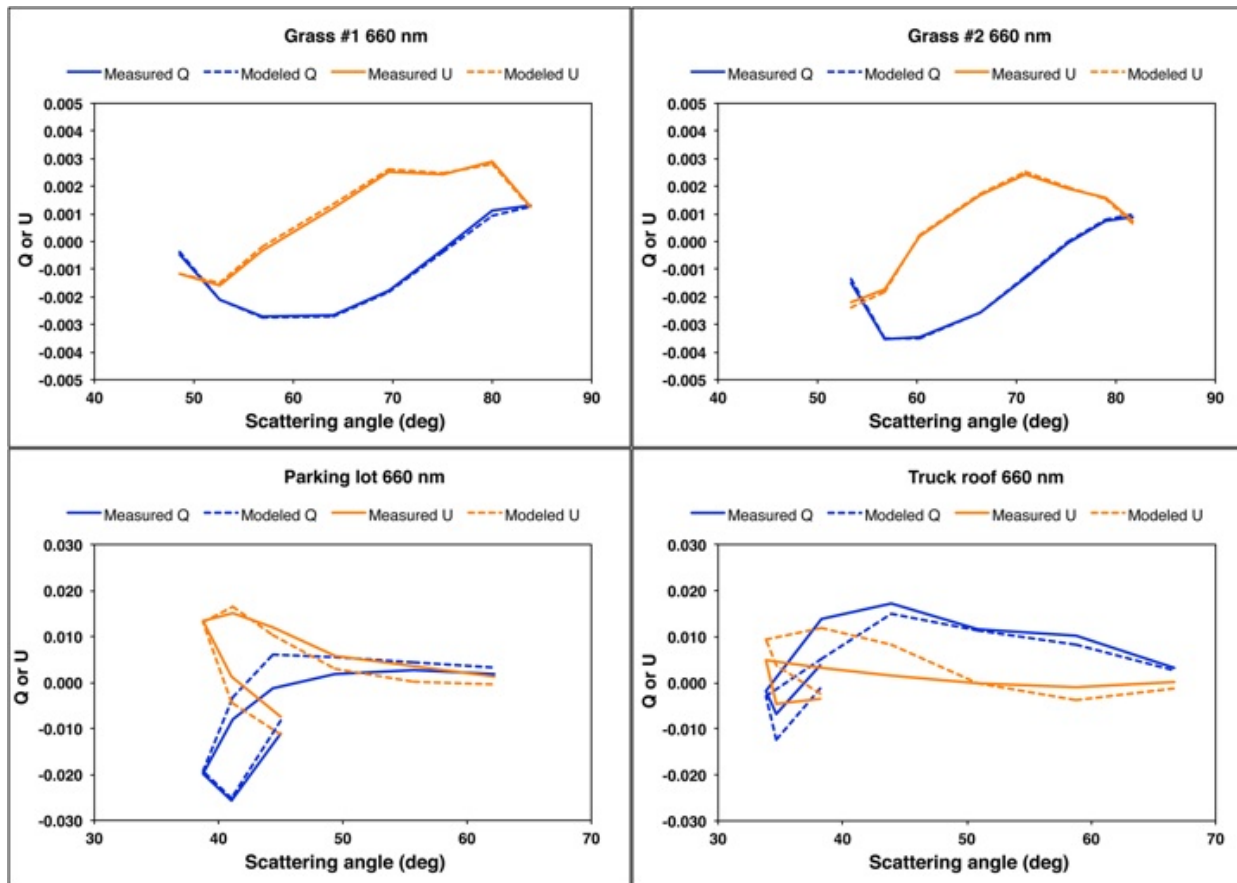


Model predicts correct functional form for natural surfaces

Does not work so well for manmade surfaces

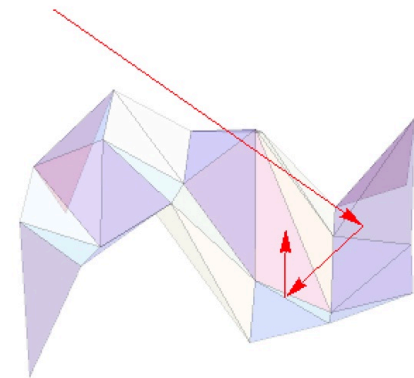
Allowance for multiple scattering

Include empirical spectrally invariant term in surface reflection matrix to allow for rotation of polarization orientation by multiple scattering

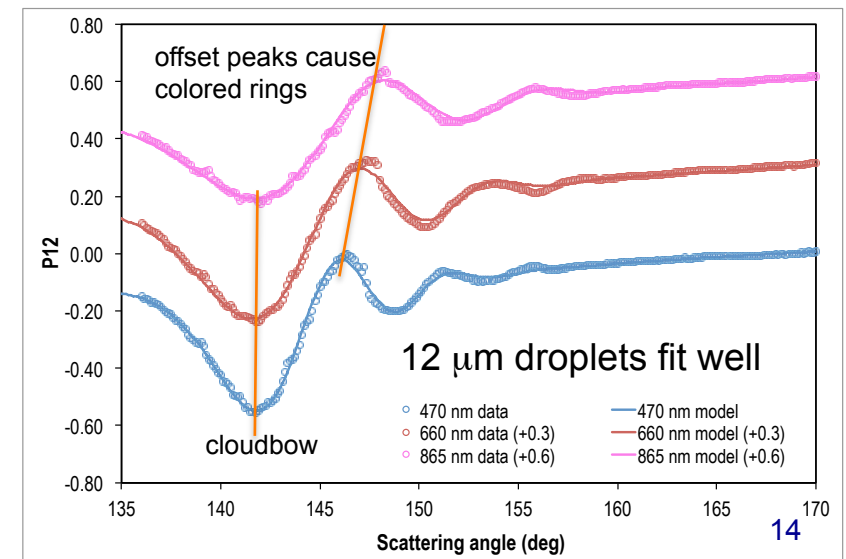
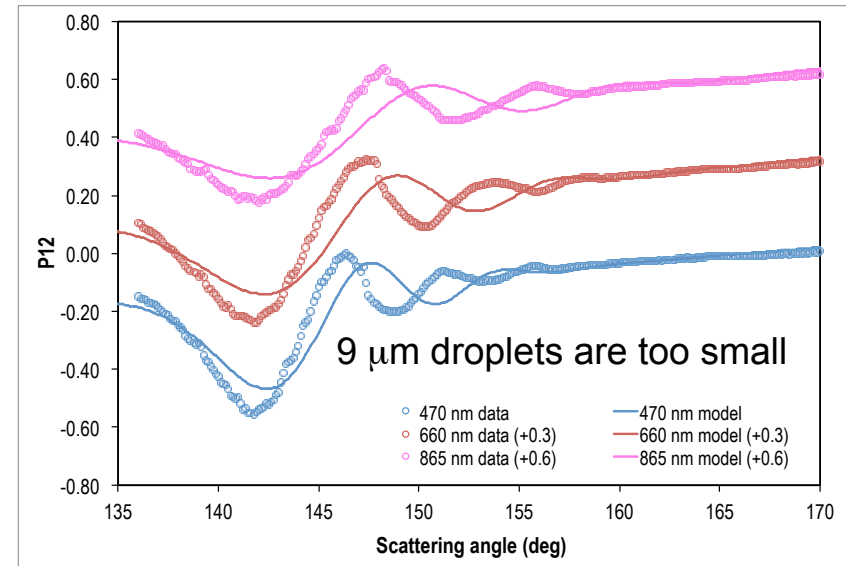
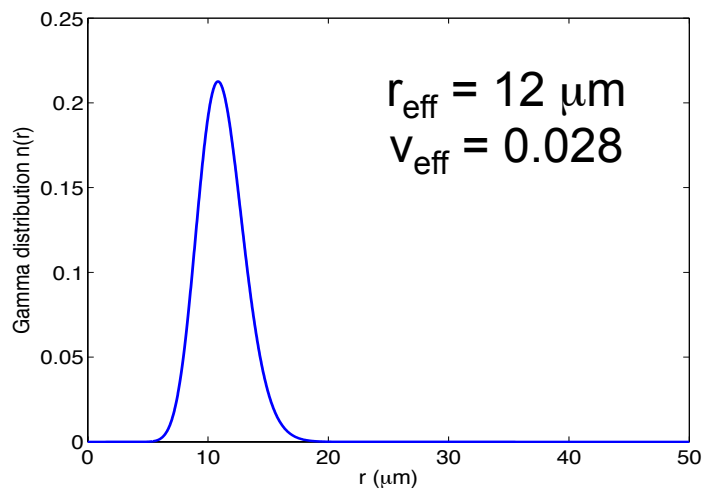
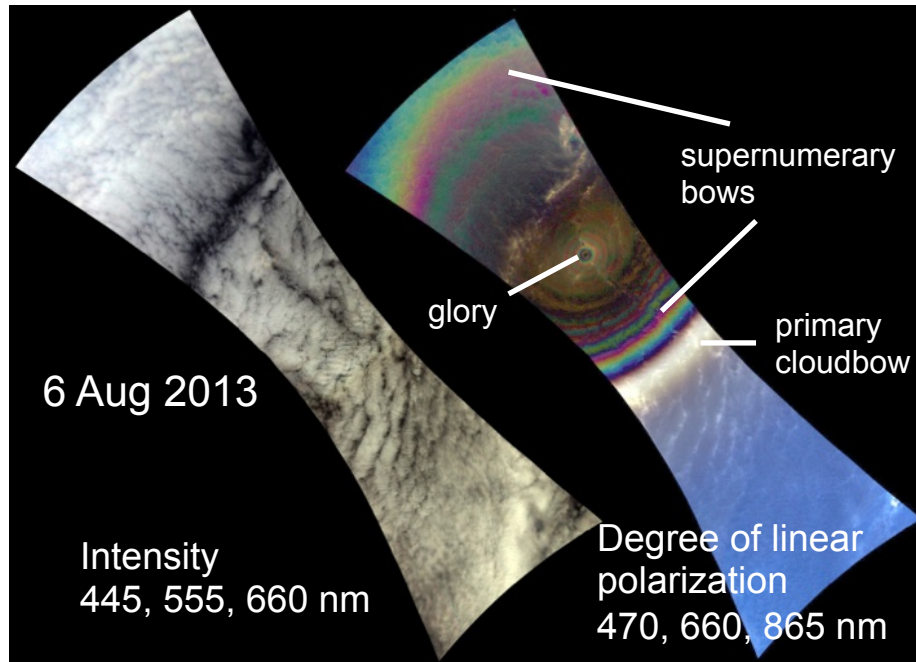


Improves the fit for all surface types

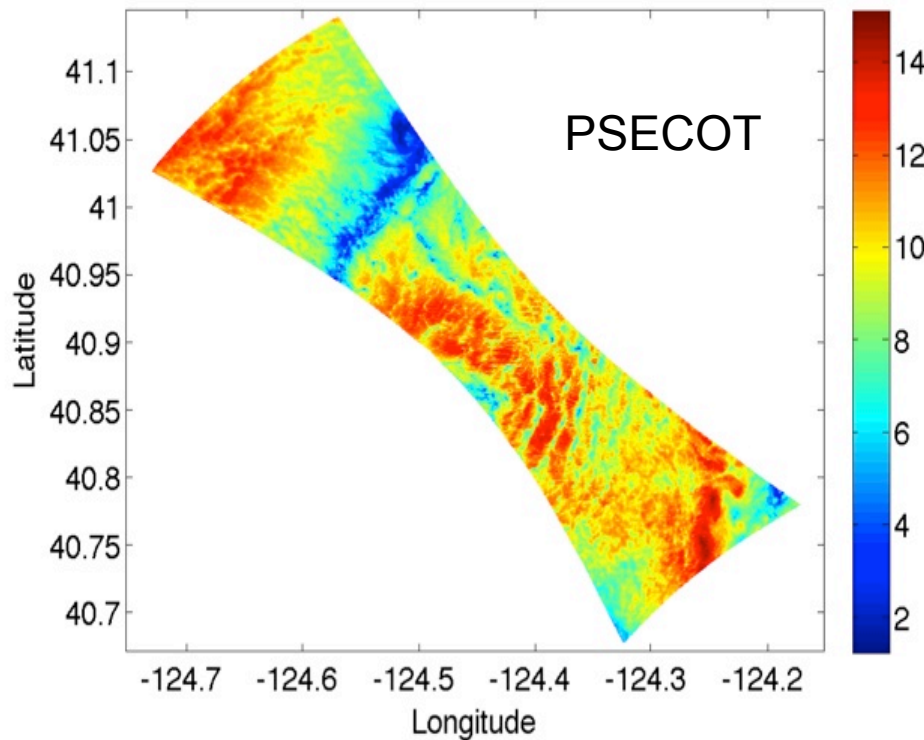
Validity of the model is currently being investigated using polarization ray tracing



Polarimetric retrieval of cloud-top droplet size distributions



Using drop size to determine bulk cloud properties



- Knowing r_{eff} and v_{eff} from polarized radiance, a look-up table is used to calculate pixel scale effective cloud optical thickness (PSECOT) from the intensity field
- PSECOT is biased by 3D (pixel adjacency) effects, leading to radiative smoothing
- Averaging to determine COT requires determination of the radiative smoothing scale η

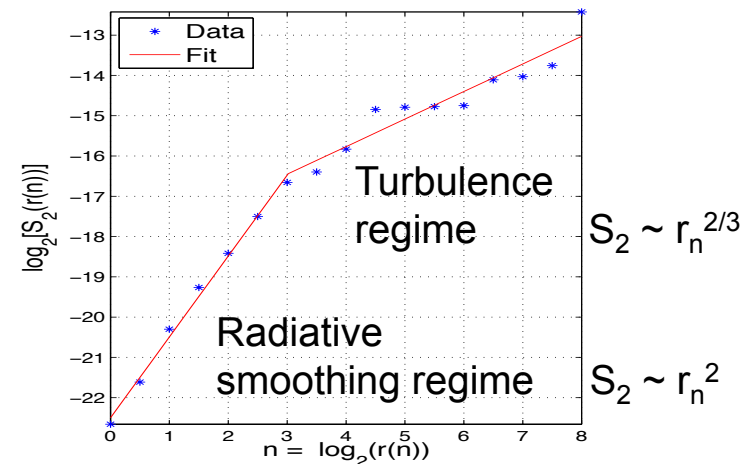
$S_2 = 2^{\text{nd}}$ order structure function: spatial (x,y) and azimuthal (ϕ) average of $|I(x+r_n \cos \phi, y + r_n \sin \phi) - I(x,y)|^2$

c = value of n at slope discontinuity

$\eta = p \times 2^c \sim 2 \text{ km} \rightarrow \text{COT} = \langle \text{PSECOT} \rangle_{\text{scale } \eta}$

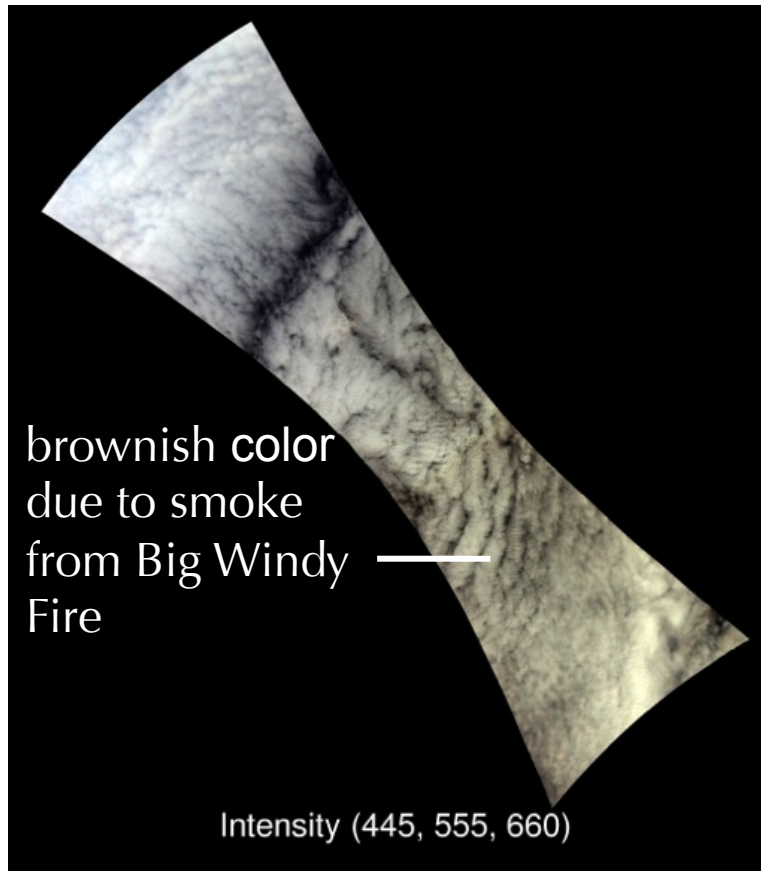
Radiative diffusion theory predicts:

- η is proportional to geometric thickness/ $\text{COT}^{1/2}$

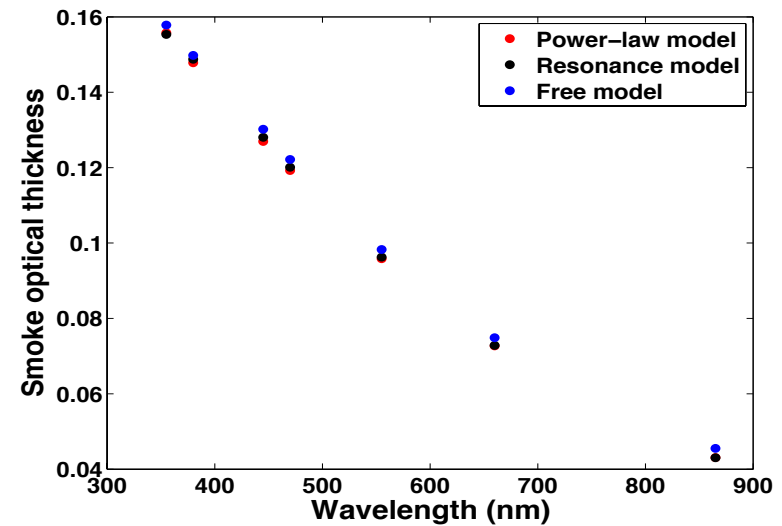
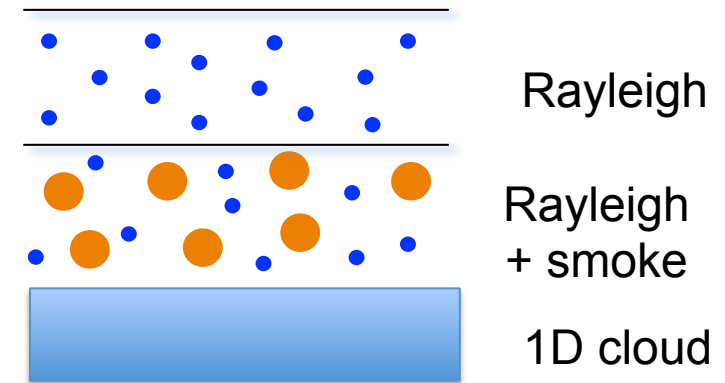
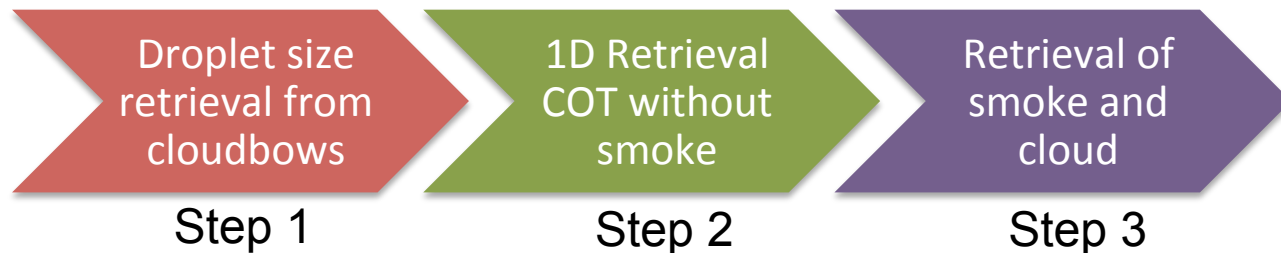


$r_n = p \times 2^n$,
where $p = 25 \text{ m}$ pixel scale

Using cloud model to retrieve aerosol above cloud

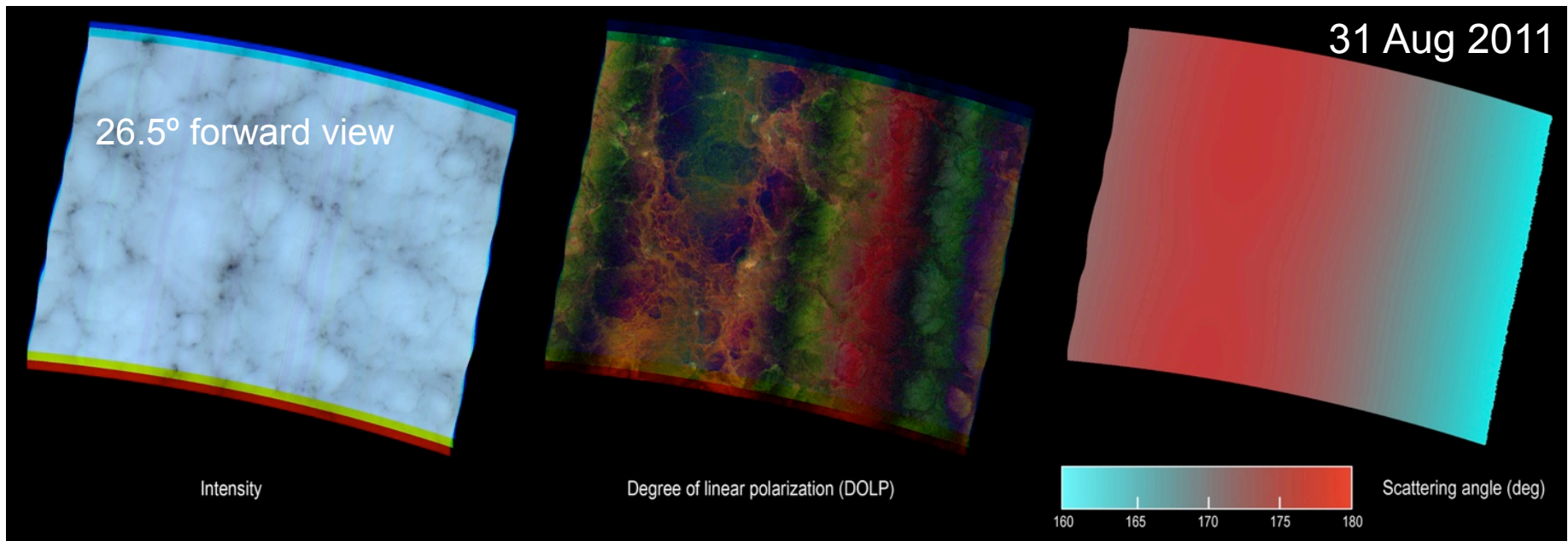


Retrieval scheme

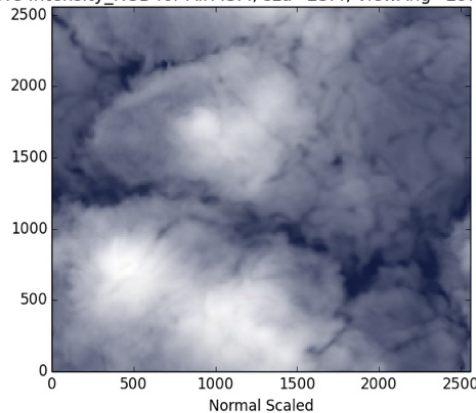


Fine-scale spatial structure in polarized backscatter

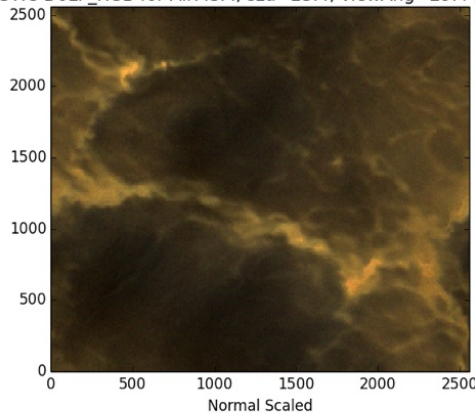
Near-backscattering step-and-stare images provide unprecedented view of turbulent dynamics at the tops of marine boundary layer clouds



MYSTIC Intensity_RGB for AirMSPI, sza=23.4, viewAng=29.4 phi=180



MYSTIC DoLP_RGB for AirMSPI, sza=23.4, viewAng=29.4 phi=180

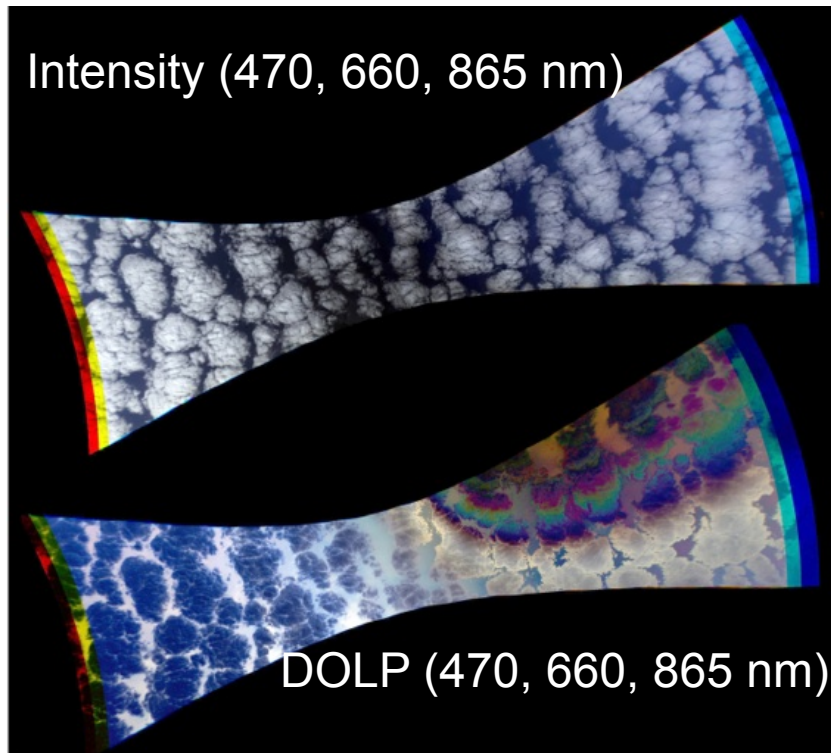


← Synthetic AirMSPI data based on bin-microphysics LES and MYSTIC 3D vRT models reproduces spatial patterns and magnitude of intensity and DOLP

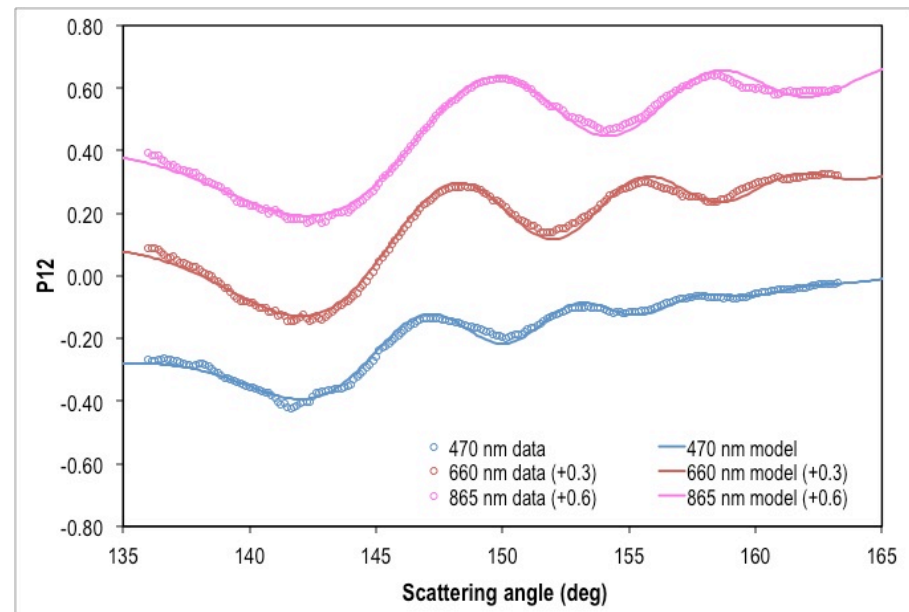
Cloudbow analysis of broken cumulus

The droplet size retrieval also works for broken clouds

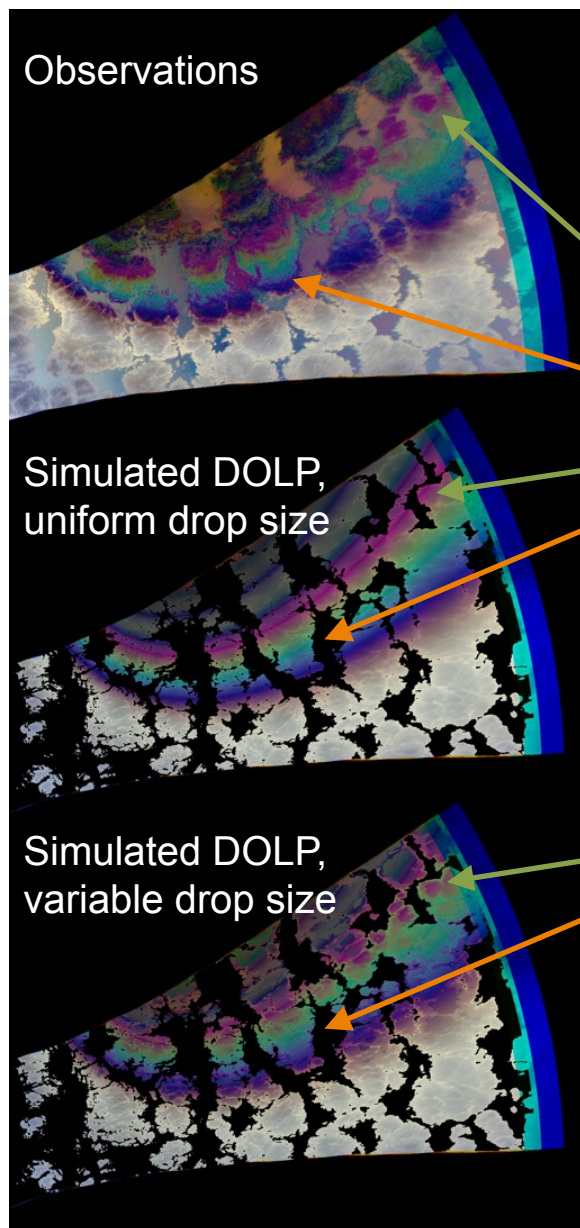
Simple spectral intensity thresholds were used to separate clouds from ocean. Data for the whole scene were fitted with with a distribution having an effective radius of $10\text{ }\mu\text{m}$ and effective variance of 0.01



6 February 2013, 2226 UTC -
Pacific sweep image



Supernumerary bow simulations



Use of a single droplet size does not reproduce the spatially resolved observations, but provides a starting point for a more complete scene model

“Scalloped” and “ringed” appearance of supernumerary arcs is not reproduced by assuming constant droplet size of $10\text{ }\mu\text{m}$

Allowing droplet size to vary from $8\text{ }\mu\text{m}$ to $10\text{ }\mu\text{m}$ in proportion to cloud brightness gives a better scene model

This is consistent with smaller sizes at the cloud edges due to evaporation or condensation as the cloud convectively thickens

AirMSPI L1 data are available at the LaRC ASDC

https://eosweb.larc.nasa.gov/project/airmspi/airmspi_table

Atmospheric Science Data Center

Processing, archiving and distributing Earth science data at the NASA Langley Research Center

Home Data Descriptions Order Data Citing ASDC Data Help & Resources

Extended Maintenance June 2-9... details

AirMSPI PODEX Ellipsoid-projected Georegistered Radiance Data

L1B2 Ellipsoid-Projected Georegistered Radiance and Polarimetry Data

Project Title: AirMSPI
Discipline: Clouds
Level: L1
Platform: NASA ER-2
Instrument: AirMSPI
Spatial Coverage: California
Spatial Resolution: Swath about 15km by 10km
Temporal Coverage: 01/14/2013 - 02/15/2013
Temporal Resolution: Variable
File Format: HDF-EOS

Reverb: [Order Data](#)
Quality Summary: [AirMSPI Data Quality Summary, V003 Products](#)

Browse Images by Date	Browse Images by Target	Parameters	Order Data	Documentation
<ul style="list-style-type: none">2013-01-142013-01-282013-02-06	<ul style="list-style-type: none">2013-01-162013-01-31	<ul style="list-style-type: none">2013-01-182013-02-01	<ul style="list-style-type: none">2013-01-222013-02-03	

NASA Official: John M. Kusterer
Site Curator: NASA Langley ASDC User Services - Contact Us
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Copyright Information

PODEX products (designated v003) were delivered in 2013.

Subsequent PODEX effort has focused on refining radiometric, spectral, geometric, and polarimetric calibration. An updated PODEX delivery will take place in a few months.

Atmospheric Science Data Center

Processing, archiving and distributing Earth science data at the NASA Langley Research Center

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Extended Maintenance June 2-9... details

AirMSPI SEAC4RS Terrain-projected Georegistered Radiance Data

AirMSPI Terrain-Projected Georegistered Radiance Product

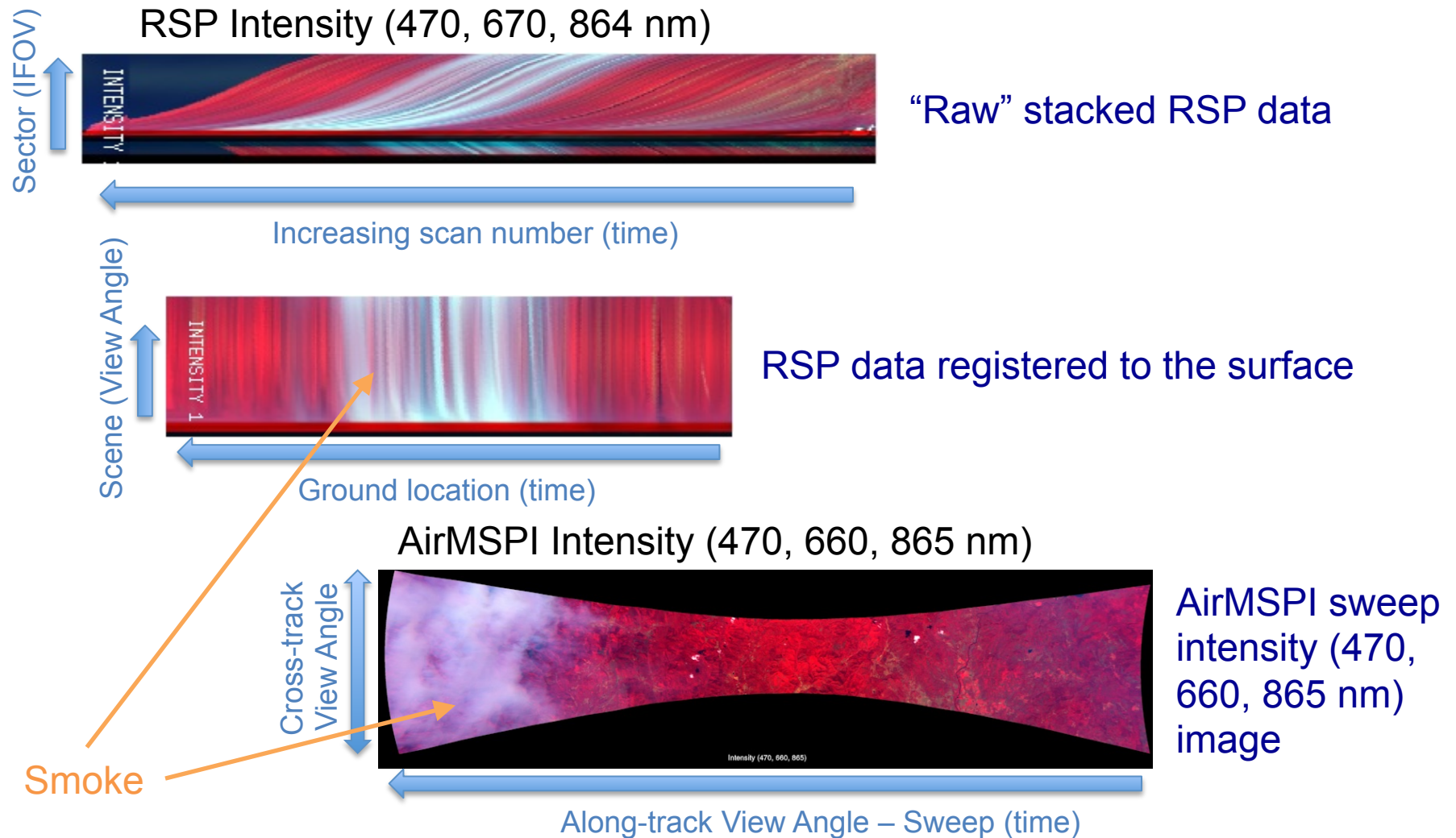
Project Title: AirMSPI
Discipline: Clouds
Level: L1
Platform: NASA ER-2
Instrument: AirMSPI
Spatial Resolution: Swath
Temporal Coverage: 08/01/2013 - 09/23/2013
Temporal Resolution: Variable
File Format: HDF-EOS

Reverb: [Order Data](#)
Quality Summary: [AirMSPI Data Quality Summary, V004 Products](#)

Browse Images by Date	Browse Images by Target	Parameters	Order Data	Documentation
<ul style="list-style-type: none">ArkansasBakersfieldCentralTexasCottonwoodFresnoInyoNyeLasVegasLosAngelesNortheastArkansasNorthWestTexasPaintedDesertSacramentoValleySantaBarbaraSantaMonicaBaySouthwestKansasSpringMountainsTorranceValenciaTorranceWestNebraska	<ul style="list-style-type: none">ArmadosaBibbCibolaDelNorteHellinKneelandLebecLouisianaNorthernCaliforniaPacificPoplarBluffSanClementeIslandSantaCatalinaIslandShastaLakeSouthwestNebraskaSpringMountainsLasVegasTucsonVisaliaYubaCity	<ul style="list-style-type: none">ArmadosaPahrumpCaliforniaOregonCibolaValenciaEastTexasHotSpringsKressLincolnMontereyNorthTexasPahrumpPutnamSanJoaquinValleySantaCruzIslandSierraNevadaMountainsSouthwestOklahomaThunderBasinValenciaVisaliaFresno	<ul style="list-style-type: none">AshlandCarmelClairemontFowlerInyoLamontLincolnChavesNipomoNorthwestKansasPahrumpSpringMountainsSacramentoSanLuisObispoSantaMariaSoutheastMissouriSouthwestOregonToledoBendValenciaLincolnWatsonville	

Several calibration improvements were made for SEAC⁴RS. Publicly available SEAC⁴RS products are designated v004.

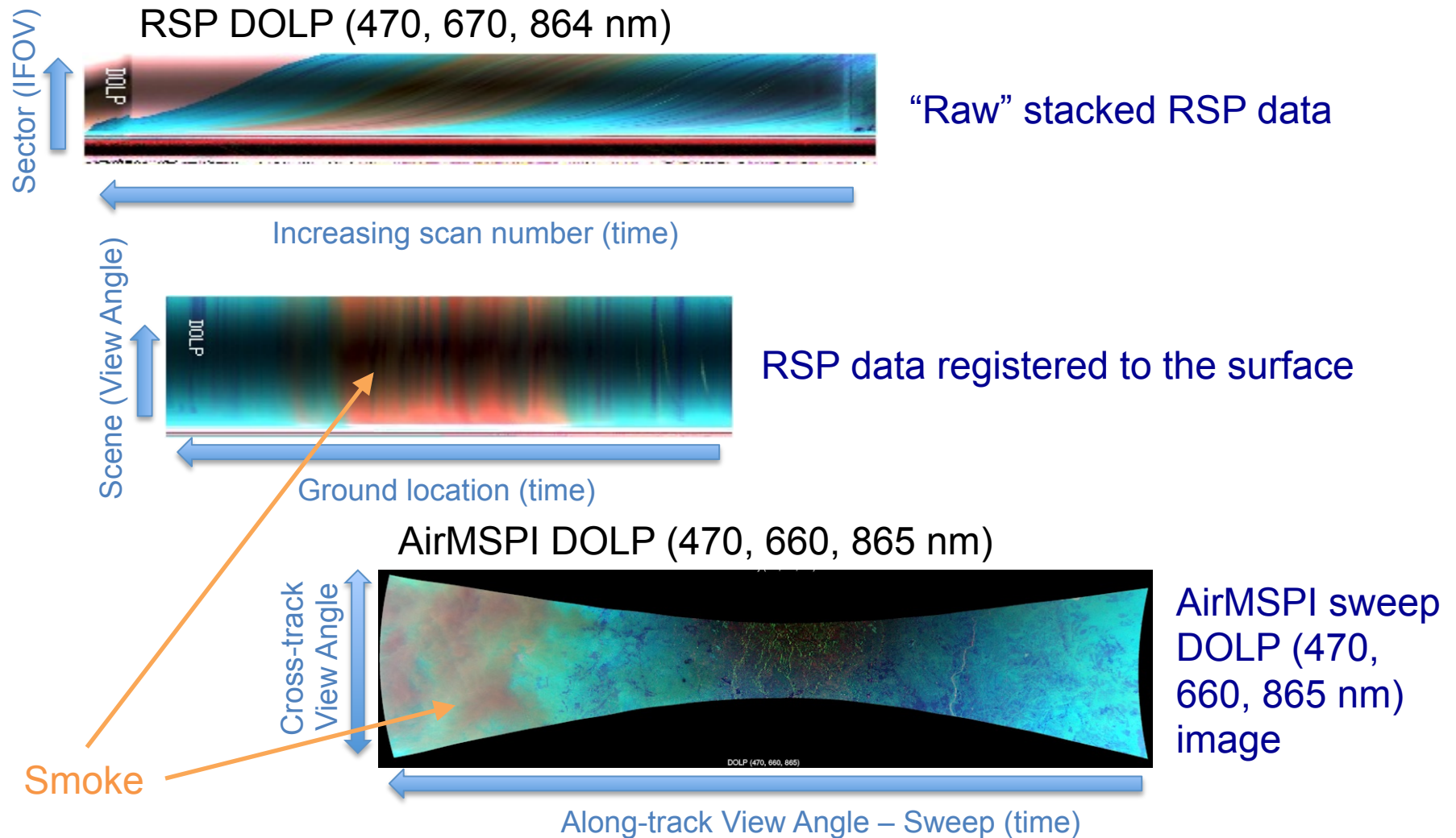
Example matchup of RSP and AirMSPI intensity



2 August 2013, 2036 UTC – Klamath Mountains (AirMSPI)
2033 UTC (RSP)

RSP data credit: B. Cairns

Example matchup of RSP and AirMSPI DOLP



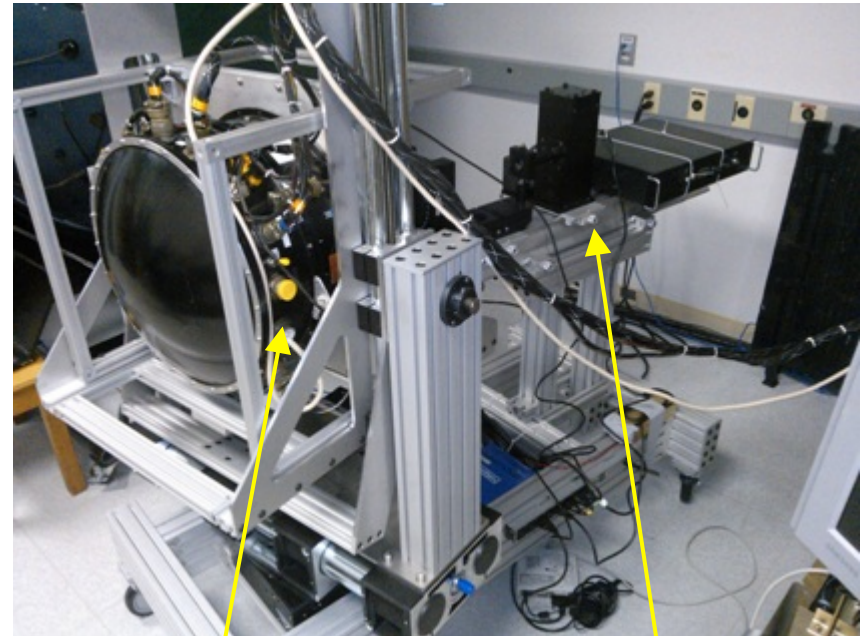
2 August 2013, 2036 UTC – Klamath Mountains (AirMSPI)
2033 UTC (RSP)

RSP data credit: B. Cairns

Laboratory polarimetric cross-calibration of AirMSPI, RSP, PACS?

- Geo-registration of AirMSPI, RSP, and PACS may be a significant source of uncertainty in cross-comparison of flight data
- Propose conducting a laboratory cross-calibration as a controlled experiment
- AirMSPI uses a highly accurate Polarization State Generator (PSG) to polarimetrically calibrate
- Russell Chipman (UofA) has offered to oversee a cross-calibration experiment using the PSG with all 3 instruments, if feasible

Polarization State Generator (PSG)



AirMSPI mounted on automated stage

PSG mounted on fixed rail

Acknowledgments

AirMSPI engineering and operations

Brian Rheingans, Sven Geier, Sebastian Val, Steve Adams (JPL),
Karlton Crabtree (Univ. of AZ)

AirMSPI science

Michael Garay, Olga Kalashnikova, Anthony Davis, Michael Tosca (JPL),
Larry Di Girolamo (Univ. of IL), Ralph Kahn (GSFC), Roger Marchand (Univ. of WA)

AirMSPI calibration

Carol Bruegge, Felix Seidel (JPL),
Brian Daugherty, Russell Chipman (Univ. of AZ), Ab Davis (Univ. of TX)

AirMSPI and GroundMSPI retrieval algorithms, software, and data archiving

Veljko Jovanovic, Michael Bull, Earl Hansen, Eric Danielson, Feng Xu (JPL),
Oleg Dubovik (Univ. of Lille), Christine Bradley (Univ. of AZ),
Pamela Rinsland, Lindsay Parker (ASDC)

Flight ops

Stu Broce, Dean Neeley, Tim Williams, Denis Steele, Tim Moes, Chris Miller (AFRC)

Sponsors

Hal Maring, David Starr, Dong Wu, George Komar, Parminder Ghuman (NASA)